Sirius. By S. W. Burnham, M.A.

It may not be generally known, even by those who have given special attention to observing or investigating the *Sirius* system, that all the collections of the measures of the companion hitherto published are not only very incomplete with respect to the number of measures which have been made, but contain many material errors in the observations quoted and made use of. Errors of one sort and another, first made long ago, have been handed down, and, remaining unchallenged, have come to be overlooked altogether. Many years ago I undertook to collect all the measures that have been made of every known double star, and the more important notes and papers referring to them, and have since added the current measures and observations, so that the history of each double star is substantially complete to this time. I have endeavoured to make these references to *Sirius* cover the various points of interest connected with it as a double star, commencing with the investigation which resulted in the discovery of the companion by Mr. Alvan G. Clark, and especially to include all measures of the small star since the first observation in 1862. The time will soon come when a complete list of these measures will be more important than it has been heretofore, for the close determination of the real period of this interesting binary. Down to this time the result must necessarily be only approximate, since the companion has moved through less than 90° of its orbit, and the real dimensions of the apparent ellipse cannot be rigidly determined. In a few years more, and probably as soon as the companion can be seen by any telescope now in use, it will have added 180° to the arc already passed over, and then a single measure will enable the period to be computed with a very small percentage of error. This important additional measure I trust can be made with the Lick telescope within the next four or five years.

In view of the new interest which this system will then have for both the observer and the computer, I have thought it important to make as perfect a collection as possible of the published observations for the benefit of all concerned. In nearly every instance I have referred to the original publication, and there obtained the figures here given. In many cases this has been necessary to avoid the errors frequently made by taking the measures from second-hand sources. As an illustration of this, I may mention one or two examples.

In some of the collected observations, Challis is credited with having measured the companion in 1862. As a matter of fact he did not measure it, and, so far as I know, never attempted to. This measure was really made by Chacornac. Gledhill gives a different result to both Challis and Chacornac, which doubtless

led to a repetition of the same error by Gore and Howard in their computations of the orbit.

Each one of these authorities has given a set of measures by Mitchel as made in 1863. This is an obvious mistake, as it is well known that General Mitchel for some time previous to this was in the military service of the United States, and engaged in the more important work of suppressing the rebellion. He died in October 1862. These measures were really made by Marth, not in 1863, but in 1864. Marth did not observe *Sirius* in 1863 at all, although he is put down as having done so by the authors previously referred to.

Gore gives a measure in 1885 credited to the Paris Observatory; and Howard includes this with the measures used in computing a new orbit published a few weeks ago (Gould's *Astronomical Journal*, 235), and also gives a measure in 1884 from the same observatory. These two measures are as follow:—

	°	″	
1884·27	36·3	8·70	Paris Obs.
1885·11	34·1	8·09	Paris Obs.

Now these two measures are identical in date, angle, and distance with the observations of Young in 1884 and 1885, and, as I have found no authority elsewhere for these measures, I conclude that they should have been credited to Princeton instead of Paris.

To enable those who wish to consult these measures to do so conveniently, I have given, following the measures, a complete list of the works in which every measure cited can be found. The authors of the papers are given in alphabetical order, but the names of all the observers do not appear in this way, as in some instances the measures of other observers are included under one name. It should be remarked also that some of the references do not relate to micrometrical measures, but have some other special interest, and should be included in a list of valuable papers on *Sirius*.

The following are the measures I have collected:—

Measures of Sirius.

1862.

	°	″		
1862·19	84·6	10·07	Bond	3*n*
1862·20	85·0	10·09	Rutherfurd	5*n*
1862·23	84·5	10·42	Chacornac	2*n*
1862·28	83·8	(4·92)	Lassell	1*n*

1863.

	°	″		
1863·21	82·5	10·15	Otto Struve	2*n*
1863·15	88·4	7·63	Secchi	1*n*
1863·21	81·3	9·54	Rutherfurd	6*n*
1863·23	84·9	10·00	Dawes	1*n*
1863·27	82·8	...	Bond	1*n*

1864.

1864·14	79°·4	10″·60	Marth	3n
1864·18	80·1	9·63	Lassell	1–3n
1864·22	78·6	10·70	Bond	4–2n
1864·22	74·8	10·92	Otto Struve	6–3n
1864·23	84·9	...	Dawes	1n
1864·24	79·7	10·08	Winnecke	1n

1865.

1865·21	77°·6	10″·59	Otto Struve	2n
1865·22	75·5	9·59	Secchi	8n
1865·23	77·8	10·77	Förster	5–4n
1865·25	76·9	...	Tietjen	3n
1865·26	76·0	...	Bond	...
1865·26	76·9	(9·0)	Engelmann	1n

1866.

1866·07	77°·2	10″·43	Knott	2–1n
1866·21	...	10·74	Bruhns	1n
1866·21	75·2	10·93	Otto Struve	3n
1866·22	73·9	10·97	Tietjen	2–1n
1866·23	74·1	11·29	Förster	3–1n
1866·23	74·0	10·21	Hall	2–3n
1866·23	74·9	10·57	Newcomb	3n
1866·25	78·3	10·34	Tuttle	1n
1866·26	74·7	10·09	Eastman	3n
1866·29	71·3	10·11	Secchi	3n

1867.

1867·02	74°·2	11″·15	Winlock	7–6n
1867·10	73·8	10·66	Searle	6–5n
1867·22	72·1	10·98	Otto Struve	1n
1867·24	72·3	...	Förster	2n
1867·27	74·9	9·92	Eastman	2–1n

1868.

1868·02	73°·2	10″·25	Searle	2n
1868·04	72·1	...	Peirce	1n
1868·23	70·3	11·25	Vogel	7n
1868·24	69·6	11·35	Bruhns	5n
1868·26	71·7	10·95	Engelmann	5n

		1869.		
1869·10	74°·7	10″·26	Brünnow	7–4*n*
1869·15	73·6	11·23	Vogel	3*n*
1869·20	68·7	11·17	Dunér	1*n*
1869·20	68·6	11·07	Winlock	2*n*
1869·23	69·4	10·93	Peirce	1*n*
		1870.		
1870·13	68°·1	11″·16	Peirce	12–4*n*
1870·17	65·9	11·06	Winlock	7–5*n*
1870·24	65·1	12·06	Vogel	5*n*
		1871.		
1871·16	65°·9	10″·75	Secchi	3*n*
1871·20	70·3	11·19	Peirce	2–1*n*
1871·23	64·1	11·11	Dunér	2*n*
1871·25	60·1	12·10	Pechüle	4–3*n*
		1872.		
1872·18	59°·8	11″·05	Dunér	2*n*
1872·24	62·4	11·50	Newcomb	1*n*
1872·24	64·3	11·46	Hall	6*n*
1872·26	61·3	...	Skinner	3*n*
		1873.		
1873·20	65°·8	11″·12	Hall	1*n*
1873·22	60·8	10·57	Dunér	1–4*n*
		1874.		
1873·93	65°·0	11″·29	Wilson & Seabroke	1*n*
1874·16	59·0	11·46	Newcomb	7*n*
1874·19	58·7	10·99	Holden	2–1*n*
1874·23	58·0	11·10	Hall	2*n*
		1875.		
1874·83	57°·5	″ ...	Burton	1*n*
1875·19	57·1	10·73	Dunér	4*n*
1875·21	56·6	11·41	Newcomb	2*n*
1875·21	55·9	11·89	Holden	5–4*n*
1875·28	56·4	11·08	Hall	4*n*

		1876.		
1876·03	57°·8	11″·12	Watson	1*n*
1876·05	54·6	11·45	Peters	1*n*
1876·09	54·9	11·82	Holden	6*n*
1876·14	55·0	11·55	Russell	4*n*
1876·22	55·2	11·19	Hall	6*n*
		1877.		
1877·11	52°·8	11″·19	Cincinnati	4–3*n*
1877·16	52·8	11·35	Holden	4*n*
1877·26	53·4	10·95	Hall	5*n*
		1878.		
1877·97	52°·4	10″·83	Burnham	8*n*
1878·07	50·5	11·07	Holden	4*n*
1878·15	51·0	10·71	Cincinnati	9*n*
1878·19	54·4	11·24	Pritchett	5*n*
1878·22	53·2	11·4	Eastman	...
1878·24	51·7	10·76	Hall	5*n*
		1879.		
1878·70	50°·0	10″·61	Cincinnati	20–14*n*
1879·05	50·7	10·44	Burnham	10*n*
1879·12	47·8	11·35	Holden	5*n*
1879·15	50·3	10·78	Pritchett	5*n*
1879·20	50·1	10·55	Hall	6*n*
		1880.		
1879·75	46°·5	10″·29	Cincinnati	1*n*
1880·00	48·8	10·55	Russell	1*n*
1880·10	47·1	10·48	Holden	4*n*
1880·11	48·3	10·00	Burnham	11*n*
1880·17	49·6	9·87	Hough	3*n*
1880·22	51·1	...	Smith	1*n*
1880·25	47·8	10·30	Hall	8*n*
1880·28	48·6	10·38	Frisby	2*n*
		1881.		
[illegible]1·07	46°·3	9″·77	Burnham	8*n*
1881·12	43·3	10·83	Holden	2*n*
1881·17	46·9	10·11	Frisby	6*n*
1881·18	46·5	9·81	Young	7*n*
1881·26	45·3	9·60	Hough	5*n*
1881·26	45·3	10·00	Hall	6*n*

1882.

1881·99	43°·6	9″·38	Burnham	11*n*
1882·13	43·1	9·30	Hough	9*n*
1882·18	42·2	9·95	Frisby	6*n*
1882·23	42·5	9·67	Hall	7*n*
1882·54	44·0	...	Engelmann	6*n*

1883.

1883·10	40°·1	9″·05	Burnham	10*n*
1883·10	39·0	9·41	Young	1*n*
1883·12	39·7	9·02	Hough	11*n*
1883·14	41·3	...	Wilson	4*n*
1883·17	41·4	9·75	Frisby	7*n*
1883·21	39·1	9·26	Hall	6*n*

1884.

1884·05	36°·0	9″·67	Perrotin	6*n*
1884·18	36·7	8·51	Hough	11*n*
1884·19	36·4	8·39	Burnham	10*n*
1884·23	37·7	8·81	Hall	8*n*
1884·27	36·3	8·70	Young	5*n*

1885.

1885·11	34°·1	8″·09	Young	8*n*
1885·20	32·7	7·96	Hough	10*n*
1885·27	34·7	8·06	Hall	8*n*

1886.

1886·05	29°·8	7″·59	Young	4*n*
1886·14	28·7	7·21	Hough	12*n*
1886·22	30·6	7·39	Hall	6*n*

1887.

1887·14	25°·4	7″·08	Young	4*n*
1887·19	23·7	6·78	Hough	7*n*
1887·23	24·2	6·51	Hall	4*n*

1888.

1888·24	23°·3	5″·78	Hall	3*n*

1889.

1888·97	13°·9	5″·27	Burnham	5*n*

1890.

1890·27	359°·7	4″·19	Burnham	3*n*

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The Period of Sirius.

Some early attempts were made to see how far the motion of the observed star agreed with the theoretical companion, but the arc described was so short, and the motion of the smaller star so nearly uniform, that no reliable result could be reached from the observations. An ellipse of almost any magnitude would satisfy the observed positions as well as one which agreed with that laid down for the theoretical star. In 1881 Plummer pointed out that a period of 440 years would represent the observations about as well as one of fifty years. Since that time the limits of the possible ellipses which could be drawn through the observed positions have been greatly narrowed by the later measures, and the uncertainty of the period of rotation correspondingly reduced.

Two orbits have been recently computed: one by Gore, using measures made each year down to 1889, who finds a period of 58·47 years; and the other by Howard, who includes the very last measures of the companion made here in 1890, and obtains a period of 57·02 years. Very few of the measures are used by the last-named computer, and some of the years are not represented at all. The measures are not always correctly given, and in one instance at least the error is a large one. This occurs in a set of measures made by me in 1877. The mean result was derived from measures on eight nights. Some of these were at the end of 1877, and some in the beginning of 1878. In the paper referred to these are given as two series: one embracing the observations of 1877, and the other those of 1878, with an error of 1″ in the latter distance. Of course, these measures all belong together, and should be represented by a single mean, as given in the original publication.

The close agreement in the periods obtained by these independent investigations is worthy of note, and perhaps no better result could be got from the material available at this time. However, I have made a rough investigation in the same direction, which is given here for what it is worth. I have followed a plan which differs somewhat from that usually adopted in this: I have taken the complete series of measures given above, and deduced from the observations of each year a result which in my judgment would best represent, so far as the measures are concerned, the position of the companion. Of course this involved a consideration of the probable merits and value of each set of measures, as derived from the skill and experience of the observer, the size of the instrument used, the number of nights,

and the general movement of the small star from the observations as a whole. It is not claimed that this method should be generally followed, since it would require a thorough familiarity with the relative value of measures by the different double star observers which many would have no opportunity of acquiring, but for the purpose I had in view in this instance it was certainly as good as any other.

The positions obtained in this manner are as follow:—

1862.20	85°.0	10″.08	1877.18	53°.0	11″.16
1863.22	82.9	9.90	1878.12	51.7	10.77
1864.20	79.6	10.38	1879.02	50.3	10.59
1865.22	77.0	10.32	1880.18	48.6	10.06
1866.21	74.5	10.39	1881.19	45.8	9.79
1867.17	73.4	10.68	1882.12	43.1	9.45
1868.16	71.4	10.95	1883.14	39.6	9.11
1869.17	71.0	10.93	1884.22	36.8	8.60
1870.15	67.0	11.11	1885.19	33.8	8.04
1871.21	65.1	11.29	1886.14	29.7	7.40
1872.22	62.2	11.34	1887.19	24.4	6.79
1873.21	60.8	11.12	1888.24	23.3	5.78
1874.19	58.6	11.18	1888.97	13.9	5.27
1875.22	56.5	11.28	1890.27	359.7	4.19
1876.22	55.2	11.19			

These positions were plotted on a sufficiently large scale to lay them down accurately to the decimal places. The time covered by the measures was separated into four-year intervals by the lines shown on the diagram (plate 5), and after repeated trials a satisfactory ellipse was drawn which would make these areas equal with slight changes in the position-angles. This ellipse gives a period of 53 years.

This result may not be any nearer the true time than the periods found by Gore and Howard, as it is undoubtedly true that an ellipse with a greater major axis, and consequently a longer period, would represent the arc already described by the companion about as well as any other. With reference to this matter, I have been influenced by one consideration which could not have been taken into account in the previous attempts to compute the period. I measured *Sirius* last year (1890) with the 36-inch telescope, but in consequence of my absence on the Eclipse Expedition to Cayenne, and the severe winter weather that prevailed on Mount Hamilton for some time after my return, *Sirius* was long past meridian before I could get it even in early twilight; the companion was therefore very hard to see at all, and the measures were made with extreme difficulty.

This I attributed to the unfavourable conditions, and expected to have no trouble in seeing and measuring the small star this year. I have tried to get it this year under very favourable circumstances, when the most difficult and close pairs were comparatively easy, and have utterly failed to see the least trace of it; I am satisfied that it is now beyond the reach of any telescope in the world. The distance, according to my measures in 1890, was $4''\cdot19$. It seems hardly possible that it could have been wholly invisible this year under the conditions named, if the diminution in the distance is only $0''\cdot7$, as it should be according to the orbits of Gore and Howard. I have, therefore, concluded that the small star is approaching *Sirius* more rapidly, and that the change in distance must be decidedly larger, and certainly not less than $1''$, and consequently have drawn the shorter ellipse as more likely to represent the real motion. According to this, the distance at the time of my last attempts to see the companion was $3''\cdot1$, and it is not at all improbable that, at this distance from a star as bright as *Sirius*, it would be lost in the overpowering brilliancy of the large star, even with the Lick telescope. For these reasons I think a period of 53 years is not likely to be too short.

If this ellipse is correct the minimum distance will be $2''\cdot4$ in 1892–5, and about the end of 1894 the distance will be the same as at the time of my last measures. At that time, therefore, I trust the large telescope will supply observations which will definitely settle most of the uncertainties in the orbit of this interesting system.

Lick Observatory:
1891 *February* 26.

Invisible Double Stars. By S. W. Burnham.

In addition to a large number of double stars which have been seen and measured in the regular way, we have now a new class of binaries which may be designated as invisible double stars, since they have never been seen, and are only recognised from certain peculiarities in their appearance or motions. What is known of them is due to comparatively recent investigations. It can hardly be said that their existence has been proven in any instance, and the *primâ facie* case made is not always very strong. This might be expected when it is considered that the inference is deduced from observations more or less in error; and as the difficulty of eliminating any real change from errors of observation much larger in amount is very great, the result must be received with a good deal of allowance, and particularly so when the time embraced by the observations is limited.

The latest additions to this class of double stars are due to the spectroscope, which has shown a periodical doubling of